SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

DTIC SELECTE MAR 2 4 1995 S G D

1a. REPORT SECURITY CLASSIFICATION

1b. RESTRICTIVE MARKINGS

2a. SECURITY CLASSIFICATION AUTHORITY

2b. DECLASSIFICATION / DOWNGRADING SCHEDULE

3. DISTRIBUTION / AVAILABILITY OF REPORT
Approved for public release
Distribution Unlimited

4. PERFORMING ORGANIZATION REPORT NUMBER(S)

5. MONITORING ORGANIZATION REPORT NUMBER(S)
95 0154

6a. NAME OF PERFORMING ORGANIZATION
University of Missouri-St. Louis

6b. OFFICE SYMBOL (If applicable)

7a. NAME OF MONITORING ORGANIZATION
Air Force Office of Scientific Research

6c. ADDRESS (City, State, and ZIP Code)
8001 Natural Bridge Rd.
St. Louis, MO 63121

7b. ADDRESS (City, State, and ZIP Code)
Bldg. 410, Bolling AFB
Washington, DC 20332

8a. NAME OF FUNDING/SPONSORING ORGANIZATION
AFOSR

8b. OFFICE SYMBOL (If applicable)
NE

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
Grant #: AFOSR F49620-94-1-0230 Handel

8c. ADDRESS (City, State, and ZIP Code)
110 Duncan Avenue Suite B115
Bolling AFB DC 20332-0001

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
61102F	2305	CS	

11. TITLE (Include Security Classification)
VI. Van der Ziel Symposium on Quantum 1/f Noise and Other Low Frequency Fluctuations in Electronic Devices

12. PERSONAL AUTHOR(S)
Peter H. Handel (Tel.: (314)553-5021)

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final Report	FROM 4/15/94 TO 10/14/94	Dec. 7, 1994	

16. SUPPLEMENTARY NOTATION

17. COSATI CODES

FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Quantum 1/f Noise Theory, 1/f Noise, Electronic Noise in Semiconductor Devices,, Quantum 1/f Effect, Bipolar Transistors, Noise in Ultrasmall Devices, Chaos, Nonlinear Dynamics

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This report acknowledges funding for the VI. van der Ziel Symposium on Quantum 1/f Noise and Other Low Frequency Fluctuations in Electronic Devices, which was organized by the author at the University of Missouri - St. Louis, on May 27-28, 1994. Like the previous symposia organized by us in October 1985, October 1986, April 1988, May 1990 and May 1992, this event brought together 24 researchers from universities, industrial and governmental research laboratories, and the industry, working in the field of Quantum 1/f Noise and other low frequency fluctuations in high - technology devices. A total of 21 papers was presented, including 6 invited papers. They mark important progress in the field, both in theory and experiment. The proceedings are still in print, and 6 copies will be appended as soon as they come out.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT
☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION

22a. NAME OF RESPONSIBLE INDIVIDUAL
Dr. Gerald Witt

22b. TELEPHONE (Include Area Code)
202/767-4932

22c. OFFICE SYMBOL

FINAL TECHNICAL REPORT

for AFOSR Grant Support of the

VI. VAN DER ZIEL SYMPOSIUM ON QUANTUM 1/f NOISE AND OTHER LOW FREQUENCY FLUCTUATIONS IN ELECTRONIC DEVICES

Submitted to the
Air Force Office of Scientific Research

Accesion For		
NTIS CRA&I		☒
DTIC TAB		☐
Unannounced		☐
Justification		
By		
Distribution /		
Availability Codes		
Dist	Avail and / or Special	
A-1		

PRINCIPAL INVESTIGATOR/Symposium Organizer: Peter H. Handel
TITLE: Professor of Physics
TELEPHONE NO. (314)5535021 or 5535931
ADDRESS: Physics Department, University of Missouri,
St. Louis, MO. 63121

19950323 000

ABSTRACT

This report acknowledges funding for the VI. Symposium on Quantum 1/f Noise and Other Low Frequency Fluctuations in Electronic Devices, which was organized by the author at the University of Missouri - St. Louis, on May 27-28, 1994. Like the previous symposia organized by us in October 1985, October 1986, April 1988, May 1990 and May 1992, this event brought together 24 researchers from universities, industrial and governmental research laboratories, and the industry, working in the field of Quantum 1/f Noise and other low frequency fluctuations in high - technology devices. A total of 21 papers was presented, including 6 invited papers. They mark important progress in the field, both in theory and experiment. To explain the subject of this Symposium , this report focuses on the description of the present state and of the research directions in the field of Quantum 1/f Noise, although other low frequency fluctuations were also included (as in the past), in order to widen the scope of the Symposium and the pool of participants. The report also presents a scientific overview of the papers presented, a list of papers, a list of attendees, and a list of participants. The proceedings are still in print at the American Institute of Physics, and will be appended to this report as soon as they come out.

In most high-technology applications 1/f noise appears as a low-frequency fluctuation or slow drift of the device parameters, which limits the achievable performance and stability. On the other hand, physical cross sections and process rates have been shown theoretically by the author to fluctuate with a 1/f spectral density according to a simple universal formula. This new formula gives the power spectrum of cross section fluctuations if the velocity change of the scattered current carriers in the process is known. We can now calculate quantum 1/f noise in all forms of scattering (impurity, phonon, umklapp, inter-valley), in bulk and surface recombination and tunneling rates, as well as emission processes. A very successful unified description of 1/f noise in electronic devices has thus been constructed with the help of vitally important AFOSR funding in an earlier phase (Grants AFOSR-84-0229 and 89-0416). The unified description and the quantum 1/f noise formula have been verified in many systems, such as vacuum tubes, secondary emission tubes, semiconductors, pn junctions, semiconductor devices, in particular infrared detectors, transistors, submicron devices, etc.. The quantum 1/f theory was used with success to reduce 1/f noise in infrared detectors, various transistors, and ultrasmall electronic devices. It was also applied with success to Josephson junctions and SQUID's, quartz resonators, laser giroscopes, and radioactive decay. Nevertheless, most electronic and electro-optic devices, including the ultrasmall devices, are still operating considerably above the theoretical limit set by the quantum 1/f noise theory. Therefore, the main objective of the participants at the present Symposium was to cooperate in this new field, in order to further reduce the 1/f noise in the known devices, and to extend the application to new devices which are now being developed, including new FETs with ultralow gate leakage currents, new infrared detectors, new compact frequency standards, and high T_c superconductors. The focus of the Symposium also included further development of the quantum 1/f theory, and its connection to studies of quantum and classical deterministic chaos in the intermediary region between conventional and coherent quantum 1/f effects. Finally, this Symposium benefited those involved in virtually all high-tech applications, through general low 1/f noise design and optimization principles, as well as through an improved understanding of the quantum 1/f effect as a technically important fundamental law of nature. Past Symposia were funded by ARO (I-III), ONR (IV) and NSF (V).

We are most thankful to AFOSR for the support of this Symposium.

CONTENTS

I. INTRODUCTION

The present report on the "Fifth van der Ziel Symposium on Quantum 1/f Noise and Other Low Frequency Fluctuations in Electronic Devices" which was held at the University of Missouri, St. Louis, MO, on May 27 and 28, 1994, brings a brief presentation of the main subjects discussed in the papers presented, a list of attendees, a list of papers, and a list of authors. The Symposium was organized by P. H. Handel with the help of A. L. Chung, similar to the previous five symposia. Like the previous ones, the present symposium was again successful in bringing together scientists and students from universities and industrial, as well as governmental, research and development laboratories working in this new field of tremendous practical and theoretical importance, vital for most high-technology applications. To describe the importance of this new field and to explain its relevance for high-tech applications, we provide in this introduction a review of recent developments and a few examples of quantum 1/f theory applications.

During the last four years we have achieved considerable progress in the field of Infra Quantum Physics which includes the conventional and coherent state quantum 1/f effects. The progress included both theory and experiment. **On the theory front**, a more rigorous derivation of the fundamental quantum 1/f effect formula in the language of second quantization was developed, and the pair-correlation function was calculated in the general case of N particles present in the final state. Progress in theory also included a calculation of the quantum 1/f cross-correlation spectra, the derivation of the effect of a finite mean free path, and a detailed calculation, with the collaboration of G. Kousik and C.M. Van Vliet, of mobility fluctuation spectra predicted by the theory. **On the experimental front**, with the collaboration of A. van der Ziel, C. Jones, W. Radford, G. Bosman, E. Kelso, Q. Peng, C.M. Van Vliet, A. van Rheenen, D. Wolf, T. Musha, and of many talented graduate students, the theory was both verified and successfully applied to many systems. The most important applications included junction-type and MIS-type infrared detectors, HEMTs, PBTs, BJTs, HBJTs, JFETs, and SQUIDs. The theory was also verified quantitatively in vacuum tubes, secondary emission tubes, photomultipliers, thin semiconducting and metallic sheets, as well as qualitatively in quartz resonators, SAW devices, piezoelectric and ferroelectric materials, in nuclear α–decay and in β–decay. With the help of measures suggested on the basis of the simple quantum 1/f effect formula, high-technology industrial laboratories were able to reduce the 1/f noise level of infrared detectors by two orders of magnitude. The hopeless uncertainty and ignorance which handicapped device builders in the past when it came to understanding, theoretically predicting and controlling 1/f noise has become a thing of the past. There is, however, no smooth transition between the conventional quantum 1/f effect theory and the coherent state quantum

1/f theory; all we have to connect these two important special cases is a heuristic interpolation formula which I suggested in 1985 on qualitative physical grounds. Furthermore, although we had a spectacular noise reduction of two orders of magnitude during the last four years in junction-type infrared detectors, most high-technology devices still operate at 1/f noise levels which considerably exceed the quantum limit given by my formula for ideal conditions. Finally, some new devices, in particular those with layered structures and those utilizing high T superconductors, have not yet been analyzed on the basis of the quantum 1/f theory, and are unnecessarily handicapped by 1/f noise. These three examples suggest and illustrate the **three main challenges** we face today: 1) Further improvement of the most important high-technology devices vital for our technology edge, and which have already been improved considerably in the past grant period on the basis of the quantum 1/f theory; 2) Application of the fundamental quantum 1/f formula to new devices, in particular to those newly developed devices, important for high-performance leading edge instrumentation, which exhibit degrading noise, parameter drift, or instability problems. Examples of such new devices are the high T_c superconducting infrared detectors and the layered devices. We hope to improve the new devices considerably by using the quantum 1/f formula. A secondary result will be further critical verification and scrutiny of the quantum 1/f theory, and growth in our experience, as well as in the ability of high-technology industries to control 1/f noise; 3) Further development of the quantum 1/f theory.

Sec. II describes the papers presented, Sec. III is a list of attendees, Sec. IV is a list of papers and Sec. V brings a list of authors.

II. SUMMARY OF THE SCIENTIFIC PAPERS PRESENTED AT THE SYMPOSIUM

Papers presented at the Symposium addressed quantum 1/f theory aspects (Widom, Handel, Zhang), 1/f noise in new materials (Tacano, Dagge et al.), general 1/f noise problematics (Van Vliet and Huisso), and 1/f noise in devices (Lukyanchikova, Koslowsky, Simoen) including ultrasmall devices (Kochelap), and VLSI circuits (Celic-Butler).

The quantum 1/f noise theory papers have addressed the relation between 1/f noise and quantum chaos, showing that quantum 1/f noise is a form of quantum chaos. Quantum mechanics itself represents chaos at a more fundamental level. Other quantum 1/f theory paper focused on the connection between coherent and conventional quantum 1/f noise, extending a bridge from the coherent side in the conventional direction.

III. LIST OF ATTENDEES

ANDERSON, JAMES
P.O. Box 85
Hopkins, MN 55343

BERNARDI, ERNEST
4127 Pennsylvania
St. Louis, MO 63118

BOSMAN, GIYS
Dept. of Electr. Engineering
University of Florida
216 Larsen Hall
Gainesville, FL 32611-2044

CHROBOCZEK, JAN A.
C.N.E.T.
P.O. Box 89
38243 Meylan, France

COLE, BOB
Xerox Corporation
11885 Lackland Rd.
St. Louis, MO 63146

DAGGE, KERSTIN
Inst. für Physik
Max-Planck-Institut für Metallforschung
Heisenbergstraße 1
D-70569 Stuttgart, Germany

DIGGINS, JOE
Quantum Circuits Group, M.A.P.S.
University of Sussex
Falmer Brighton, BNI 9QH
United Kingdom

HANDEL, PETER H.
Dept. of Physics and Astronomy
University of Missouri
St. Louis, MO 63121

KOCHELAP, Viatcheslav A.
Dept. of Theoretical Physics
Inst. of Semiconductor Physics
Kiev, 252650 Ukraine

KOSLOWSKI, BERNDT
Physics Dept.
Dalhousie University
Halifax, Nova Scotia
Canada B3H 3J5

LUKYANCHIKOVA, NATALIE
Inst. of Semiconductor Physics
Natl. Acad. Sc. of Ukraine
45 Prospect Nauki
252028 Kiev, Ukraine

MACUCCI, MASSIMO
Dip. di Ingegneria dell'Informazione:
Elettronica, Informatica, Telecomunicazioni
Università degli Studi di Pisa
Via Diotisalvi, 2
I-56126 Pisa, Italy

MIHAILA, MIHAI
ICCE Research Inst. for

Electronic Components
Erou Iancu Nicolae 32B
Bucharest 729996, Romania

PRANCE, ROBERT
M.A.P.S.
University of Sussex
Falmer, Brighton, BN1 9QH
United Kingdom

PROLEIKO, IGOR
Dept. of Physics and Astronomy
University of Missouri
St. Louis, MO 63121

SIKULA, JOSEF
Dept. of Physics
Technical University of Brno
Zizkova 17
60200 Brno, Czech Republic

DR. SIKULOVA, M.
Dept. of Mathematics
Technical University of Brno
Zizkova 17
60200 Brno, Czech Republic

SURYA, CHARLES
Dept. of Electronic Eng.
Hong Kong Polytechnic
Hung Hom, Kowloon
Hong Kong

TACANO, MUNECAZU
Corp. Tech & Plann. Div.
Kyocera Corporation
Higashino, Yamashina
Kyoto, 607, Japan

VAN VLIET, CAROLYNE M.
College of Engineering and Design
Dept. of Electr. & Comp. Engineering
University Park, ECS-347

Miami, FL 33199

WIDOM, ALLAN
Physics Dept.
Northeastern University
Boston, MA 02115

WURREY, CHARLES J.
Office of the Vice President
for Academic Affairs
309 University Hall
Columbia, MO 65211

ZHANG, RUOJIAN
Electr. Engineering Dept.
Southern Methodist University
Dallas, TX 75275

ZHANG, YUANHAN
Department of Physics and Astronomy
University of Missouri
St. Louis, MO 63121

IV. LIST OF PAPERS PRESENTED

Quantum "1/ω" Noise and Space-Like Photon Propagation (Invited)
A. Widom, Y.N. Srivastava and E. Sassaroli

SQUID Rings as Macroscopic Quantum Objects: The Quantum-Classical Interface (Invited)
R.J. Prance, R. Whiteman, H. Prance, T.D. Clark, J. Diggins, J.F. Ralph, T.P. Spiller, A. Clippingdale, A. Widom and Y. Srivastava

New Noise Problems in an Old Form: "Recycling" Fluctuation Phenomena (Invited)
C.M. Van Vliet and A. Huisso

G-R Noise in GaAs/$Al_{0.4}Ga_{0.6}As$ Resonant Tunneling Diodes (Invited)
C. Surya

1/f-Noise in Thin Aluminum Films Damaged by Electromigration
K. Dagge, J. Briggmann, C. Reuter, A. Seeger and H. Stoll

Discussion of the 1987 Conventional Quantum 1/f Noise Source Term
P.H. Handel
1/f Noise in Fluid Films
S. Cable and T. Tajima (presented at the XII. International

V. LIST OF AUTHORS

Anderson, J.
P.O. Box 85
Hopkins, MN 55343

Bosman, G.
Dept. of Electr. Engineering
University of Florida
216 Larsen Hall
Gainesville, FL 32611-2044

Briggmann, J.
Inst. für Physik
Max-Planck-Institut für Metallforschung
Heisenbergstraße 1
D-70569 Stuttgart, Germany

Brouers, F.
Physics Dept.
University of Liège, Sart Tilman
Liège 4000, Belgium

Cable, S.
Southwest Research Institute
6220 Culebra Rd.
San Antonio, TX 78238

Çelik-Butler, Z.
Electr. Engineering Dept.
Southern Methodist University
Dallas, TX 75275

F, Z.
Dept. of Physics

Technical University of Brno
Zizkova 17
60200 Brno, Czech Republic

Chroboczek, J.A.
C.N.E.T.
BP 98
38243 Meylan, France

Claeys, C.
IMEC
Kapeldreef 75
B-3001 Leuven, Belgium

Clark, T.D.
Physics Dept.
University of Sussex
Brighton, Sussex BN1 9QH, UK

Clippingdale, A.
Physics Dept.
University of Sussex
Brighton, Sussex BN1 9QH, UK

Dagge, K.
Inst. für Physik
Max-Planck-Institut für Metallforschung
Heisenbergstraße 1
D-70569 Stuttgart, Germany

Diggins, J.
Physics Dept.
University of Sussex
Brighton, Sussex BN1 9QH, UK

Gabar, N.
Inst. of Semiconductor Physics
Natl. Acad. Sc. of Ukraine
45 Prospect Nauki
252650 Kiev, Ukraine

Ghibaudo, G.
Laboratoire de Phys. de Composants

à Semicond., ENSERG
B.P. 257
38016 Grenoble, France

Handel, P.H.
Dept. of Physics and Astronomy
University of Missouri
St. Louis, MO 63121

Heedt, C.
Solid State Devices Dept.
University of Duisburg
Kommandantenstr. 60
47057 Duisburg, Germany

Huisso, A.
Centre de Recherches Mathématiques
Université de Montréal
Montréal (Québec)
H3C 3J7, Canada

Kochelap, V.A.
Dept. of Theoretical Physics
Inst. of Semiconductor Physics
Kiev, 252650 Ukraine

Koktavy, B.
Dept. of Physics
Technical University of Brno
Zizkova 17
60200 Brno, Czech Republic

Koslowski, B.
Physics Dept.
Dalhousie University
Halifax, Nova Scotia
Canada B3H 3J5

Lukyanchikova, N.
Inst. of Semiconductor Physics
Natl. Acad. Sc. of Ukraine
45 Prospect Nauki
252650 Kiev, Ukraine

Macucci, M.
Dip. di Ingegneria dell'Informazione:
Elettronica, Informatica, Telecomunicazioni
Università degli Studi di Pisa
Via Diotisalvi, 2
I-56126 Pisa, Italy

Mihaila, M.
ICCE Research Inst. for
Electronic Components
Erou Iancu Nicolae 32B
Bucharest 729996, Romania

Mounib, A.
Laboratoire de Phys. de Composants
à Semicond., ENSERG
B.P. 257
38016 Grenoble, France

Navarova, H.
Dept. of Physics
Technical University of Brno
Zizkova 17
60200 Brno, Czech Republic

Pazdera, L.
Dept. of Physics
Technical University of Brno
Zizkova 17
60200 Brno, Czech Republic

Petrichuk, M.
Inst. of Semiconductor Physics
Natl. Acad. Sc. of Ukraine
45 Prospect Nauki
252650 Kiev, Ukraine

Pogany, D.
Lab. de Phys. de la Matière
INSA de Lyon
69621 Villeurbanne, France

Prance, H.
Physics Dept.
University of Sussex
Brighton, Sussex BN1 9QH, UK

Prance, R.J.
Physics Dept.
University of Sussex
Brighton, Sussex BN1 9QH, UK

Ralph, J.
Physics Dept.
University of Sussex
Brighton, Sussex BN1 9QH, UK

Reuter, C.
Institut für Mikroelektronik
D-70569 Stuttgart, Germany

Sasseroli, E.
Physics Dept.
Northeastern University
Boston, MA 02115

Schauer, P.
Dept. of Physics
Technical University of Brno
Zizkova 17
60200 Brno, Czech Republic

Seeger, A.
Inst. für Physik
Max-Planck-Institut für Metallforschung
Heisenbergstraße 1
D-70569 Stuttgart, Germany

Sikula, J.
Dept. of Physics
Technical University of Brno
Zizkova 17
60200 Brno, Czech Republic

Sikulova, M.

Dept. of Mathematics
Technical University of Brno
Zizkova 17
60200 Brno, Czech Republic

Simoen, E.
IMEC
Kapeldreef 75
B-3001 Leuven, Belgium

Spiller, T.D.
Physics Dept.
University of Sussex
Brighton, Sussex BN1 9QH, UK

Srivastava, Y.N.
Physics Dept.
Northeastern University
Boston, MA 02115

Stoll, H.
Inst. für Physik
Max-Planck-Institut für Metallforschung
Heisenbergstraße 1
D-70569 Stuttgart, Germany

Surya, C.
Dept. of Electronic Eng.
Hong Kong Polytechnic
Hung Hom, Kowloon
Hong Kong

Tacano, M.
Corp. Tech & Plann. Div.
Kyocera Corporation
Higashino, Yamashina
Kyoto, 607, Japan

Tajima, T.
Institute for Fusion Studies
University of Texas
Austin, TX 78712

Tegude, F.J.
Solid State Devices Dept.
University of Duisburg
Kommandantenstr. 60
47057 Duisburg, Germany

Vanhellemont, J.
IMEC
Kapeldreef 75
B-3001 Leuven, Belgium

Van Vliet, C.M.
College of Engineering and Design
Dept. of Electr. & Comp. Engineering
University Park, ECS-347
Miami, FL 33199

Vasina, P.
Dept. of Physics
Technical University of Brno
Zizkova 17
60200 Brno, Czech Republic

Whiteman, R.
Physics Dept.
University of Sussex
Brighton, Sussex BN1 9QH, UK

Widom, A.
Physics Dept.
Northeastern University
Boston, MA 02115

Zhang, R.
Electr. Engineering Dept.
Southern Methodist University
Dallas, TX 75275

Zhang, Y.
Department of Physics and Astronomy
University of Missouri
St. Louis, MO 63121